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BASIC REQUIREMENTS FOR PLANNING AND CONDUCTING OPERATIONS ON THERMAL STRENGTHENING OF GROUND

- USSR -

By I. M. Litvinov

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TABLE OF CONTENTS — Page

This brochure sets forth the principal requirements for planning and conducting operations of thermal strengthening of loess-like and other clay grounds which are porous and subject to setting.

It is written for engineers and technicians working in scientific research, planning, and construction organizations.

Foreword

Loess grounds subject to settling are developed in many countries, especially in the South of the Soviet Union. The construction practice knows many instances of considerable and uneven settling of the foundations of buildings and constructions as a result of the compaction of such grounds because of their moistening and the load. This brings about dangerous deformations conducive to building hazards and often leads to the total collapse of a structure. At the same time, a great number of major buildings and structures have already been erected and are now being erected on grounds subject to settling.

The problem of the reliable strengthening of settling grounds is important and urgent, inasmuch as its solution will promote construction in the areas of such grounds without the hazard of subsequent damage.

Many investigators have proposed various methods of strengthening loess grounds. However, these methods either do not meet the requirements, or else call for a great expenditure of time, effort and money.

The Southern Scientific Research Institute for Industrial Construction (YuZhNII), Academy of Construction and Architecture, Ukrainian SSR, in cooperation with the "Zaporozhstroy" Trust of the Ministry of Construction, Ukrainian SSR, has worked our thermal and thermochemical methods of strengthening loess grounds. Their application fully eliminates the settling tendencies of grounds and considerably strengthens their bearing capacity.

Laboratory experiments have shown that not only loess and loess-like loams but loess-like chernozems (humus loams), subjected to thermal strengthening, become safe and unyielding foundations for any construction with their coefficients and angles of internal friction, as well as their cohesion, considerably increased.

Experimental research on the verification and promotion of these thermal methods was done in the YuZNII and in trusts "Zaporozhstroy," "Dzerzhinskstroy," and "Nikolpl'stroy" of the Ministry of Construction, Ukrainian SSR, by I. M. Litvinov and Candidate Tech. Sc. Ostashev, in cooperation with N. F. Belyakov, L. A. Gelis, A. K. Linovskiy, G. K. Lubents, V. S. Posyada, N. A. Rusakova, V. P. Chernyshev, and I. D. Fal'kov.

Consultation and information on the application of thermal consolidation of settling and other grounds can be obtained at the Academy of Construction and Architecture, Ukrainian SSR (Kiev, Vladimirskaya, 24, Presidium AC and A, Ukrainian SSR) and at YuZhNII (Kharkov, Yumovskaya, 16).

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GENERAL

Thermal methods do away with the settling propensity of loess and other porous clay grounds and increase their carrying capacity at a depth of 10-15 m and more below the foundations.

The application of thermal methods of ground consolidation is technically and economically efficient in the following instances:

a) in consolidating loess-like grounds subject to settling of categories two and three, under newly-erected large apartment buildings and industrial, special, and other constructions which do not stand uneven settling (blast furnaces, factory smokestakes 100 m high and higher, water towers, various tall structures, coking plants, steel foundries, rolling plants, critical technological installations, many-storied solid wall and frame housing and industrial buildings, etc);

b) in eliminating further damage to buildings already affected by intensively developing uneven settling;

c) to combat landslides, and in a number of other instances.

Thermal consolidation of ground can be achieved in two ways:

First method (proposed by N. A. Ostashev) is to pump into the ground through heat resisting pipes and wells compressed air previously heated to 600-800°C in special stationary or portable heating units.

This method may prove to be effective in areas of operating plants where it is possible to utilize the vented hot gases with temperatures not lower than 500°C, or else where the second method is impractical because of the local conditions of installing firing chambers and jets necessary for its operation.

This brochure sets forth the conditions for planning and operating the second method of ground consolidation.

Second method (proposed by I. M. Litvinov, F. A. Belikov and P. K. Cherkasov) is based on a thermal and thermochemical processing of grounds by hot gaseous combustion products enriched when necessary by special chemicals (thermochemical method). Fuel (gaseous, liquid, or solid) is burned directly in the ground or else at well heads, with the chemical composition of the combustion products regulated by an addition of proper chemicals. As a result of the ground's reaction with hot products of combustion (solid, liquid, or gaseous), either during the operation or after it, a consolidation of the ground is achieved; thermal, thermochemical, or a combination of the two.

The possibility of regulating the temperature of this process by varying the volume of air for one kilogram of fuel or one cubic meter of fuel gas, along with the wide temperature range thus obtained (up to 2000°C), renders this method applicable not only in consolidating loess-like grounds of considerable thickness but for other construction purposes requiring a fusing of the ground.

To intensify the penetration of hot air into the ground, a pressure head must be maintained by pumping compressed cold air into injection wells. A higher pressure head sharply increases the efficiency of the thermal process, both technically and economically. The

The main prerequisite for such a high pressure head is an airtight well-head and a permeability reduction in the upper ground zone.

The maximum temperature of the combustion products in the well should not exceed the fusing temperature of the ground. The fuel expenditure per unit of time is established depending on permeability of the ground for gas.

This method calls for a less complicated equipment and is less laborious than the first one, which considerably broadens the field of its application.

Various gaseous, liquid, and solid fuels can be used in this process. Fig 2 illustrates a ground consolidating installation by thermal method, operating on liquid fuel. A similar installation is used for gas fuel.

The use of gas fuel considerably facilitates the firing and warming up of the injection well; it produces a more even heating of its walls, and consequently of the formation; it simplifies the temperature regulation, thus creating conditions more favorable for preventing the walls from fusing; and it considerably cuts the operating costs.

The fuel burns either at the well-head or else directly in the formation. The well-head is made airtight by a special shut-off device. Hot gaseous combustion products, without an outlet, penetrate the ground pores and heat the formation to the temperature required.

Given an adequate capacity of the air pump maintaining a pressure head of 0.25-0.50 atm in wells, a simultaneous consolidating operation can be carried on for large segments of the ground.

Heat is transferred to the surrounding ground chiefly as the result of a penetration of hot gaseous combustion products and air into the formation pores, and to a smaller extent by heat transfer due to the temperature difference at the contact between the heat source and the formation.

Loess-like grounds so treated completely lose their settling propensities and no longer become soft when wet; their resistance to compression, shear, and compaction is increased many times; the settling of wet grounds under a load ceases immediately; and their color changes (from pale pastel hues to brick red).

Equipment

Equipment for thermal consolidation of ground consists of units readily assembled on the spot.

The following are used in operations with <u>liquid fuel</u>:

1) pumping units for conveying outside air to the wells, at 0.5 atm (compressors, pipelines, etc);

2) jets for burning liquid fuels in injection wells;

3) shut-off devices with combustion chambers at the well-head;

4) a pumping unit, or one using compressed air to convey liquid fuel to the well;

5) a pipeline system with valves and pressure gages for compressed air (0.5-1.0 atm) and liquid fuel.

The following are used in operating with gas fuel (in gas-supplied areas or in those with coke-chemical plants and other industrial plants yielding waste fuel gas):

1) installations for pumping outside air into the injection wells at 0.5 atm (same as for liquid fuel);

2) gas jets for burning gas fuel in wells;

3) shut-off devices with combustion chambers (same as for liquid fuel);

4) master compressor or air blower for injecting fuel gas into wells at 0.5-1.0 atm;

5) a pipeline system with valves and gages for compressed air (0.5-1.0 atm) and fuel gas.

There is no need for a gas compressor in areas of oil and gas fields where various fuel gases are already stored in pressure tanks with reducer valves.

Equipment used in the thermal consolidation of ground must satisfy the following basic requirements:

1) the assurance of a reliable, uninterrupted, and complete combustion of fuel in a well or some other installation of a limited diameter, and tightly sealed at the well-head (in both vertical and inclined boreholes or in any other device);

2) simplicity and speed (not over 15-20 min) of firing up the heating installation;

3) reliable uninterrupted operation of the heating installation over a long period of time;

4) reliable and simple control of the volume of fuel and air expended during the operation, as well as of the gas temperature in the well;

5) an even distribution of hot gases over the depth (or length) of the borehole;

6) control of the average gas temperature in the injection well to obtain optimum conditions for the thermal processing of grounds.

The YuZhNII has designed and checked under field conditions the following simple equipment for thermal consolidation of grounds, satisfying all these requirements (other models are possible as long as they satisfy these requirements):

1) jets for burning liquid and gas fuel in wells sealed tightly at their heads;

2) portable pumping units for simultaneous pumping of liquid fuel into 12-14 injection wells and more or less adapted for conveying liquid fuels into the wells by compressed air;

3) gas and air blowers for pumping gas fuel into wells at 0.5-1.0 atm, serving as compressors when necessary;

4) a gas tank distributing gas to the wells;

5) an air-collector tank distributing compressed air to the wells;

6) an air and gas meter for the actually consumed air and gas;

7) mechanized equipment for drilling wells;

8) coring devices for taking samples of thermally consolidated formations.

Jet nozzles (Fig 3) are used in the burning of, in the closed space of a well, a definite volume of liquid fuel, corresponding to the specific conditions of thermal consolidation.

Fuel and air enter the burner under pressure; the fuel enters through its central tubing which has a nozzle with diameter dependent on the fuel and its consumption rate; air enters through the surrounding tubes.

A nozzle-diameter of 0.3 mm is recommended for diesel oil; the diameter may be larger for heavier fuels and gas. The rate of fuel flow is regulated by means of a pumping device (see below) and by a needle valve. When necessary, the needle can close and clean the nozzle outlet.

In burning of liquid fuel (oil, residual oil, vat residue, etc.) as well as gas, a burner is used where air is conveyed through an inner hollow stem, while the fuel goes through an outer tubing at pressures of 0.6-1.0 atm and then emerges through an annular slit concentric to the air vent. The torch is regulated through control of the fuel slit by means of a pilot wheel with a micrometric screw.

In operating with gas fuel, the burner illustrated in Fig 4 is recommended.

In addition to the air necessary in burning of fuel, more air is conveyed to the well (through the burner and shut-off device); this air, upon mixing with the combustion products, lowers the temperature in the well to the specified degree.

The flow of air necessary in spraying and burning the fuel, as well as in lowering the well temperature, is controlled by the burner's valves.

Airtight shut-off devices with combustion chambers may be of any design, provided they satisfy the following requirements:

1) a maximum possible sealing-off of the well-head to prevent an ascape of fuel gases and a drop of the pressure head below 0.25--.50 atm;

2) a convenient firing-up of the well and a satisfactory operation;

3) a convenient observation of the temperature and pressure of gas fuel in the well;

4) operational safety;

5) simplicity of building and installation at a location;

6) standard equipment obtainable from stores.

One such shut-off device consists of two basic parts: above the surface, a lid of welded steel or cast iron; below the surface, a refractory combustible chamber.

Given below is the description of three approved shut-off models with Fig 5 illustrating a general view of the above-ground part of a well.

One model of the shut-off device is used for liquid fuel (Fig 6). Welded to the metal lid is a sleeve for attaching the burner, a pipe with peephole and a pressure gauge elbow, and a tube for additional air. The burner is fixed to the shut-off by means of two wedges which assure its rapid installation and an airtight connection.

The tube with a peephole and a gauge elbow leads directly to the combustion chamber, thus affording an observation of the burning process and the pressure in the well.

In order to assure an even distribution of the excess air coming from above so that it would not get too close to the flame torch and perchance blow it out, the inside of the lid has a cone and a cylinder with an annular flange, so as to have a slit 5-7 mm wide between it and the cone.

In this model the combustion chamber is formed by three ceramic (refractory) funnels. The upper ceramic element, of a special form (manufactured by the Zaporozh'ye and other factories), has a cylindrical ring on top for attaching it to the metal shut-off lid. The middle and lower funnels are standard. The upper and middle funnels, joined by their bases, form the combustion chamber. The lower funnel lengthens the chamber and is used together with tube 9 in conveying additional air essential in firing up the well. The air flow through tubes 3 and 9 is regulated by valves.

During the operation, the burner is attached fast to the metal lid by means of a wedge lock.

A second shut-off model (Figs 7 and 8) is recommended for gas fuel. In operations with liquid fuel, this simplified model may be used only by experienced workers who know how to fire up a well without lower air. This model has no lower refractory funnel and no tube for conveying excess air to the lower element of the combustion chamber.

A third model (Fig 8) can be used in operations on open platforms in the thermal consolidating of grounds under new buildings to be constructed. This model consists of three elements: a massive cast iron upper lid, a cast iron combustion chamber with a stabilizing slab, and a ceramic facing of the well-head.

The upper lid has a short conic length of tubing for the burner, a sleeve with an inside thread for attaching the peephole tube with a gauge elbow, and a bell mouth to distribute the excess compressed air regulating the gas temperature in the well, along the periphery of the combustion chamber.

The lower element of a cast iron shut-off device consists of a cylindrical tubing which forms the combustion chamber and a slab diameter of 1500 mm with a spur to the ground to render the shut-off device more airtight.

The tubing has a sleeve for conveying compressed air to the well-head and a flange for fastening the shut-off lid.

The ceramic facing of the well-head consists of a standard funnel used in metallurgy for pouring steel.

A portable pumping unit is used in conveying liquid fuel to burners. (Liquid fuel can be conveyed by gravity flow from tanks installed 5-8 m above the well-head). Such an installation (Figs 10 and 11) consists of a type G-11-11A gear pump, electromotor, switch, and pressure gauge, all mounted on two tanks coupled to make a single body. Valves connecting hoses to the burners fit into their sides.

To maintain the necessary pressure of fuel driven by this pump to the burners, the pumping unit has a special regulator valve with a scale; this device assures bypassing of excess fuel to the outer loop of the pipe line. The fuel pressure is checked to 0.1 atm by a gage installed on the pump.

Depending on the number of outlet valves, one such pumping unit services as many as 12-14 wells with fuel. However, a gear pump is capable of servicing no fewer than 20-30 wells by switching it to a distributing chamber with a corresponding increase in the number of outlet valves.

Fuel is pumped directly from the tank through a benzoresisting hose or a metal tube with a mesh filter.

The flow of fuel is controlled with a special attachment consisting of a 560 cm^3 measuring cylinder (effective capacity 500 cm^3) with a T-valve. The control attachment is fitted between the pump and the fuel tank. By determining the emptying rate of the fuel cylinder with a stop-watch, the actual consumption of fuel is determined for various readings of the pressure gage.

A simplified and less powerful pumping unit for the simultaneous servicing of only 10-12 wells can be obtained by converting a small automobile pump, the M-20 No. 20-101 101-V type (see catalogue of spare parts for the passenger "Pobeda" car M-20), operated by a 0.27 kwt motor.

Another installation for the pressure-pumping of fuel to burners works by compressed air. This model consists of two coupled tanks mounted on the common welded frame (Fig 12). The tanks are connected by T-valves through which -- alternately for each tank -- compressed air is conveyed from above at 2.0-2.5 atm; liquid fuel is conveyed from below and, driven by the air pressure, proceeds through a pipe to the gas collector, from which it is distributed to the injection well burners.

While one of the tanks is operating, the other is being filled with fuel.

Fitted in the lower part of each tank are measuring tubes which afford constant control of the fuel level in a tank. The tanks also have pressure gauges.

Gas blowers are used in driving fuel gases with a low pipe line pressure (0.005-0.1 atm) into wells with a 0.25-0.50 atm pressure head.

An RMK-2 vacuum pump manufactured by the Bessonov Compressor Plant can be used for an air blower. This pump is capable of maintaining a pressure head up to 1.3 atm. (Fig 13). This model consists of a water-ring pump, an A-61 10 kwt motor and a gas collector all mounted on a portable steel frame. The operation requires 10 liters of water per minute. For this reason, the mounting frame should be somewhat modified by converting it into a closed reservoir. The water circulation through this reservoir is effected by means of a small auxiliary pump installed on the same frame.

The performance of a RMK-2 is characterized by the following indexes (Table 1):

Table 1

Index names	Unit of Measure	Pumping pressure in atm				
		0.3	0.5	0.8	1.0	1.3
Capacity reduced to the intake conditions	m^3/min	2.75	2.53	2.01	1.52	0.68
Ditto	m^3/hr	165.0	151.8	120.6	91.2	40.8
Effective power	kwt	6.7	7.13	7.5	8.0	8.85

At an average pressure of 0.5 atm, this gas blower services simultaneously ten wells (gas expenditure for one well varies in a range of 8-12 m^3/hr).

In operation, basic control of the gas consumption is accomplished by a valve fitted to the RMK-2, while additional control (depending on the operating conditions in each well) is exercised by the burner valves of wells.

The operating procedure and the turning on of gas fuel for the RMK-2 in thermal consolidation of grounds is as follows:

To begin with, gas and water are connected; the first to the intake pipe and the second to the vacuum pump nipple. A turn of the knife-switch cuts in the motor which, by means of a connecting sleeve, turns the vacuum pump shaft. Then the stop-cock is opened to let gas into the pump. Should the machine stop, this stop-cock also prevents the passage of water from it and to the intake pipe.

The incoming gas proceeds along the pipe to the gas collector together with water, which is fed to the pump to effect a hydraulic seal, to maintain the water ring, and to cool off the gaskets. Inasmuch as a pressure head is established in the gas collector, it drives the free water out of it through a floating level regulator - water outlet (whose operation is controlled by a water gauge) to the drainage channel (from the side opposite to the water gage); in the meantime, gas proceeds through the open valve of the outlet shaft, to the hoses, and on to the well burners.

In order to regulate the gas pressure in the collector, and because the gas must not escape into the atmosphere, the intake and pumping lines are connected by a by-pass.

The pressure is regulated by a valve. Also fitted to the gas collector is a pressure gauge, while the pipe has a back valve in front of the stop-cock.

The gas collector serves as a fuel distributor for the wells. It consists of a metal pipe 1.2-2.0 m long with a 100-150 mm diameter, with two rows of ½" tubes welded into its sides to attach the fuel gas hoses leading to the well burners (Fig 14).

Welded into the middle part of the gas collector is a gas pipe to the gas blower.

Such a gas collector-distributor makes it possible to cut in the necessary number of burners (20-30), depending on the capacity of the gas blower and compressors, also to regulate and cut off the gas for any individual burner.

Special attention should be paid to the welding and connection of parts in order to avoid gas leakage.

Various sources of compressed air can be used for conveying outside (cold) air to injection wells, to maintain the combustion, to lower the temperature, and to maintain the required pressure head for hot gases (0.25-0.50 atm): electric compressors (either portable or stationary), air pipe blowers, RMK-2 and RMK-3 vacuum pumps, blocked super-high pressure fans, etc. The use of the benzine and low-power compressors is to be avoided as very uneconomical and labor consuming; they also raise the cost of thermal consolidation of grounds.

In using even the most efficient electric compressors, the cost of compressed air is no less than 1/3 of the total operation cost. For this reason, the use of air pipe blowers, blocked super-high pressure fans, or other sources of cheaper air is recommended, as long as they provide the same well-pressure (0.25-50 atm) with a considerably higher efficiency than that of compressors.

The efficiency of compressors used in thermal strengthening of ground can be increased considerably by using the air from each of the two compression steps by means of proper switching.

An <u>air collector-receiver</u> distributes air to the wells. It consists of a metal pipe no less than ten meters long, with a 250-400 mm diameter. Welded in on both sides of one end of this pipe are tubes with a diameter not smaller than $1\frac{1}{4}$", with stop-cocks and sleeves for hoses which carry air to the burners and well shut-offs (Fig 15). Connected to the other end of the pipe are compressors or other sources of compressed air. Such an air collector has a capacity of several cubic meters; this assures a more even pressure of the air conveyed to the wells.

When compressors are used, each of the two compressing steps must be connected with the air collector with 2" hoses.

The pressure in the air blower is controlled by a gauge. Such an air blower allows an even distribution of air to the wells, as well as the turning on and off and regulation of each individual well.

The <u>control meter of actual air and gas consumption</u> (in cubic meters) per unit of time (minute or hour) per operating well is a simple device illustrated in Fig 16. It consists of two lengths of 50 mm pipe, 1,000 and 1,500 mm long, connected to the air and gas sources and consumption points, and also connected to a differential gauge by nipples welded into the pipes. The two pipes are separated by a diaphragm with a 25 mm orifice in the center of it.

Diagrams of the connection of this device, in operation, are given below.

As shown by experience, the cost of fuel gas amounts to 3-5% of the total cost of ground consolidation, with the air and drilling costs accounting for approximately 70%.

Drilling is the most labor-consuming component of the ground consolidating operations. It often happens, especially in repairing the damage to already standing buildings, that the drilling has to be done under complicated and cramped conditions (near foundations, inside the buildings, etc). Despite the comparatively small amount of drilling to be done in working by this method, the cost of it usually accounts for a considerable part of the total, amounting to 40%. For this reason, the following should be avoided:

a) hand drilling, which is laborious, time consuming and expensive;

b) complicated installations used in mechanized deep drilling which are bulky and call for a considerable service personel, power outlay, etc. The use of such complicated, although mechanized, installations is usually even more expensive than the hand drilling.

Used in drilling wells are light portable mechanized rigs designed to drill 150-200 mm holes up to 10-15 m deep, by the vibro-, pneumo-, or rotary methods.

Coring device (Fig 17). Inasmuch as thermally consolidated loess-like grounds have gained strength (up to 15 kg/cm^2 and over), their sampling with conventional laboratory methods is impossible. For this reason, the taking of samples to test for compaction and shear is recommended to be done using an electrodrill with a cutting head capable of taking a perfectly cylindrical core. The core is trimmed and separated from the main body by the same electrodrill, with the cutting head replaced by a smooth metal disc.

Planning

Thermal consolidation of grounds should be done according to a previously worked-out plan calling for all data determining the distribution and diameter of wells, the depth of thermal processing, diameters of the consolidated zones, the work schedule, and the methods of its control.

Pits, drifts, and other diggings for pressure burning can be vertical, horizontal, inclined at various angles, or combinations of these positions.

The distance between 0.15-0.20 mm boreholes or other diggings (trenches, shafts, etc.) and the distance between their axes depend on the structural features of constructions being erected or repaired, on the layout of their foundations, and on the load distribution.

With an even distribution of load on the foundation, the well plan may be a rectilinear network or a checkerboard.

Considering that the average diameter of a thermally consolidated body of ground around a well, with the operation carried out properly, is 2.0-2.5 m, the minimum distance between the well axes can be taken as 2.0 m.

The maximum distance between the well axes depends on the structural features which are capable of withstanding bending stresses between two columnar supports of buildings and their foundations.

Specifically for apartment houses and industrial buildings, the position of the strengthened zones should coincide with that of the interspan walls (Fig 18).

The depth of wells is planned depending on the thickness of the formation to be consolidated, and varies usually from six to 15 m.

The premises for thermally consolidated grounds are based on the following considerations. Properties of the main body of a consolidated zone are nearly the same within the 300-800°C temperature effect range. On the other hand, in the effective zone of higher temperatures (800-1000°C and higher) where a fusing of ground particles takes place, the strength of thermally consolidated grounds rises considerably, and may attain very high values. This, however, is not the main purpose of thermal consolidation, whose goal is merely to eliminate the setting tendency of a ground.

In calculating the strength of thermally consolidated ground, the average calculated (allowable) resistance of the supporting surface is assumed, for the entire consolidated body, to be 4-6 kg/cm^2, with a deformation modulus of 200-300 kg/cm^2.

When necessary, the actual strength of a consolidated rock column can be established experimentally by applying pressure on consolidated pillars.

The strength of a consolidated columnar body, projected to the entire thickness of the formation, can be calculated in a way similar to that for a deep columnar foundation, with the entire stress transferred from the building to the consolidated zone surface without considering the pressure transfer to the intervals between consolidated columns.

In the event, the consolidated columnar supports do not reach a non-compacting horizon, they act as driven piles under the conditions of a possible wetting and settling of the unconsolidated ground.

In view of the fact that thermally consolidated grounds not only are rid of their settling tendencies (which is the main purpose of their consolidation) but also have their strength increased no less than 2-3 times, the thermally consolidated bodies can be arranged with consideration given to the corresponding increase in allowable pressures on the strengthened segments of ground (as it is in the instance of combination piles). This will leave intervals of unreinforced ground to the extent of 66% of the overall foundation area.

In determining the distance between the wells, the columns of consolidated ground should be regarded as piles with a critical load N_c (in kg) computed with the formula

$$N_c \nless R_y F_{av} = m\, R\, F_{av},$$

where R_y is the average calculated resistance of a consolidated ground column (determined from experimental wells) in kg/cm^2;

F_{av} is the area of an averaged cross-section of the consolidated ground column, as measured in experimental wells, in cm^2;

m is factor of the increase in the standard resistance of unprocessed ground, computed depending on the depth of thermal

processing, with formulas and tables in Paragraph 13, Chapter II-B 6 SNiP;

R is the assumed resistance of ground, before thermal consolidating, in kg/cm^2.

In addition, the work plan should include measures of protecting the wells and diggings from atmospheric precipitation and other waters during the work of thermal consolidation (sufface protection and drainage, etc). In highly-gas-permeable grounds, the air tightening of wells should be accompanied by lowering of permeability in the surface layer, 0.5-0.8 m thick, by tamping, developing a surface crust, clay and concrete treating, etc.

The temperature of gaseous products in a well, with complete combustion, may exceed 2000°C. At such temperatures, gases in contact with the ground cause its fusing, which impairs the gas penetration and slows down its movement. To avoid this, the maximum temperature of gases in a well must not exceed the fusing temperature of the ground.

The fusing temperature of loess-like grounds varies within a 1200-1400°C range; repeated heating raises it by 70-100°C.

The maximum temperature of gaseous combustion products is achieved with a minimum possible amount of air necessary for the chemical process of combustion.

The minimum volume of air, V_o, necessary in the combustion of 1 kg fuel is as follows:

1) for diesel fuel with heating capacity Q_r= 10,000 kg. cal/kg, $V_o = 11.2\ m^3/kg$;
2) for pipeline crude with Q_r = 10,300-10,900 kg.cal/kg. V_o = 11.5-12.2 m^3/kg;
3) for residual oil with Q_r = 9740 kg.cal/m^3, V_o = 10.9 m^3/kg;
4) for coke gas with Q_r = 4300-4820 kg.cal/m^3, V_o = 4.805.4m^3/m^3;
5) for generator gas with Q_r= 1350-1440 kg.cal/m^3, V_o = 1.5-1.6 m^3/m^3.

The temperature of gases formed in combustion can be regulated by changing the volume of air conveyed to the well. The excess air introduced into a well does not participate in the chemical reaction of combustion, but mixes with the combustion products and lowers their temperature. Moreover, it serves as an additional heat carrier as it penetrates the ground pores.

The theoretically possible temperature t_r of gases in a well (not taking into account the heat losses) can be determined from the formula

$$Q = 0{,}00673 \cdot a \cdot d^2 \sqrt{\frac{P}{T}} \cdot \sqrt{\frac{h}{(r+f)\cdot(0{,}904+f)}}$$

where Q is heating capacity of fuel, in kg.cal/kg or kg.cal/m^3;
V_a is volume of air conveyed to well per 1 kg of fuel, in m^3;
C_p is average heat capacity of combustion products, by weight, at constant pressure P and assumed to be 0.235 + 0.000019 t_r in kg.cal/kg.deg.

The approximate theoretical relationship between the amount of air conveyed per 1 kg fuel and the gas temperature in the well, using liquid fuel (solar oil or diesel fuel) is given in Table 2.

Table 2

V_B, m^3/k^2 / V_O, m^3/k^2	1	1,5	2	2,5	3	3,5
V_B, m^3/k^2	11,2	16,8	22,4	28	33,6	39,2
t_r, degrees	2300	1670	1300	1050	896	785

The volume of air V_a conveyed to a well should be 2.5-3 times larger than the minimum necessary for complete combustion of fuel.

To avoid the fusing of ground in wells and to obtain optimum conditions for its thermal processing, the volume of air conveyed to a well should be 25-30 m^3 for each kilogram of liquid fuel with an assumed heating capacity of about 10,000 kg.cal/kg. Correspondingly, 10-15 m^3 air should be conveyed for 1m^3 coke gas with a heating capacity of 4300-4820 kg.cal/m^3. These volumes are given for 0°C outside temperature and atmospheric pressure of 760 mm mercury column, to conform to formulas and tables for air volumes determined by differential gage.

The amount of air penetrating into the ground around a well depends on the gas permeability of the ground and on the well pressure; it should be determined experimentally by a trial blow. For loess grounds with a 8-20% moisture content, the amount of air penetrating the formation is usually 10-40 m^3/hr per 1 m of the well depth.

A linear relationship between the air consumption and the length of a well may be assumed as a first approximation.

In planning the thermal consolidation of a ground area, the amount of air, V_a, necessary for an optimum thermal process under the condition of complete combustion of fuel and a corresponding cooling of the combustion products (as computed in cubic meters per 1 kg of liquid fuel or 1 m^3 gas fuel) is established, depending on the projected temperature of burning gases in a well, from the formula or Table 2 given above. For instance, at a projected well temperature of 1000°C, and for solar (diesel) oil as fuel, the amount of air should be V_a = 29 m^3, with V_a = 9 m^3 for coke gas, etc.

The amount of fuel for one running meter of the well length, per hour, is computed depending on its heating capacity, the gas permeability of the ground, its fusing point, the moisture content and the specific gravity. For instance, for a projected well temperature of 1000°C and gas permeability of 20 m^3/hr for one running meter of the well, no more than 20/29 = 0.69 kg solar oil per hour is required, or not over 6.9 kg for a 10 m deep well; and not over 20/(9 + 1) = 2m^3 coke gas per one running meter, or not over 20 m^3/hr for the same ten meter-deep well.

An increase in the amount of fuel consumed per unit of time brings about a rise in temperature above the projected, with fusing of the well walls as a result, which is inadmissible; a fused well is rejected and a new one must be drilled beside it.

These data afford an approximate estimate of the fuel consumption in airtight wells. They are derived from the results of experimental well firing, determining the amount of air penetrating one running meter of the well wall at various pressures, and the optimum flow rate for air and fuel consumed per one running meter of well depth.

Given in Appendix I is an example of calculating the amount of liquid and gas fuel and the time necessary for the burning of a single 12 m deep well with a consolidated zone diameter of 2 m and a ground moisture content of 12.5%.

The following approximate data can be used in tentative calculations of the amount of fuel, air, and time necessary in the thermal processing of ground to a depth of 10 m and with the diameter of the consolidated zone of 2 m.

The hourly liquid fuel expenditure for one running meter of a well is 0.4-0.5 kg, or 4-5 liters for the total depth; the corresponding amounts of gas fuels are 1.0-1.2 m^3 and 10-12 m^3.

The hourly air expenditure with liquid fuel is 25 m^3 for 1 kg of fuel, or 100-125 m^3 per well; the corresponding figures with gas fuel are 10 m^3 for one 1 m^3 and 100-125 m^3 per well.

Time consumed is ten days, or one day per one running meter of well.

A single borehole, diameter d = 0.15-0.2 m, operating for 8-10 days, stabilizes a segment of ground, diameter D = 1.5-2.5 m, and 8-10 m deep.

With a longer period of thermal consolidation, the zone so processed may attain a diameter D = 3 m and over, with a depth of 15 m and better; this corresponds to 100 m^3 of consolidated ground per well. However, in some instances, depending on the specific conditions of the ground structure, an extreme lengthening of the burning period achieves only an optimum result (D = 2.0-2.5 m) and does not go beyond it. This limit is characterized by a drop in the efficiency of further thermal processing because of the sharp gas pressure drop in wells; this is due to gas leakage in the upper near-well interval; the cross-section of this interval grows larger as the humus additions are burned out and the ground structure is broken up.

Under normal conditions, i.e., with a 0.25-0.50 atm pressure head and a comparatively homogeneous ground, the growth of a thermally consolidated block proceeds by zones distributed more or less equally about the well, with a slight downward narrowing (Fig 19-a). In the Dnieper region building practice of the Ukrainian SSR, an 8-12 day firing of an 8-12 m deep well produced a consolidated ground column diameter of 2.0-2.5 m.

Under unfavorable working conditions (an insufficient or totally absent pressure head in a well or else its inadequate shutting off), a

conic (Fig 19-b) instead of a cylindrical consolidated zone is obtained; this is inadmissible.

The presence of open wells for future firing (or already fired) about a fired hole (Fig 20) improves its firing conditions by improving the gas circulation from the lower intervals of operating wells. In firing, every other well is operated.

Thermal strengthening of ground is planned in I, II, III, and IV cycles (turns or groups) with a simultaneous operation of the corresponding number of wells for each cycle (Figs 18 and 20-24).

The number of cycles depends on the total number of wells to be fired, but mostly on the capacity of the air conveying equipment and on the availability of flexible and benzo-resisting hose.

To speed up the operation, the number of cycles (turns) should be as small as possible. Thus, in strengthening the ground under the foundations of industrial smokestakes and tall segments of buildings as well as in repairing damage caused by local wetting of ground subject to settling, when only 6-30 wells are needed, they should be fired in 1-2 cycles; this will require 10-20 days.

The duration of each cycle (burning up the required amount of fuel in wells under specified conditions) is about ten days, fluctuating one way or another, depending on the well depth, the specified diameter of the consolidated zone, and the capacity of equipment used in pressuring the wells.

The number of simultaneously fired wells (in a cycle or turn) is determined by the equipment capacity, primarily by that of the compressed air sources (compressors, air blowers, etc.)

It also should be taken into consideration that the connection of burners and shut-off devices to the sources of air and fuel requires a considerable length of durite hose of various diameters. To save such hose, it is recommended to replace it, whenever possible, by metal pipes, and to use the flexible hose only in couplings. This is especially important in the use of liquid fuel, the distribution of which to wells calls for the scarce benzo-resisting hose.

The number of burners must correspond to that of simultaneously fired wells of a cycle, plus two to three spare ones. Care should be taken in operating with liquid fuel that work would not be stopped for lack of spare needles to clean the burners' orifices.

It is recommended to have a supply of metal well shut-off devices sufficient for two cycles, in order to cut down the working time.

A ceramic element of the shut-off device, the refractory combustion chamber, and the lower air supply tube (see first shut-off model) can be used only once; accordingly, their number must correspond to the total number of wells, including the control ones.

The combustion chamber with a shut-off device installed at the well-head is protected by Mark 100 concrete mixed with red brick rubble.

In operation, every other well of a cycle is fired, with the intermediate wells serving as vents and thus improving the circulation conditions for hot gases in the lower zone of the ground being processed.

In order to have a better idea of actual expenditres of fuel, air, and time in thermal strengthening of 1 m^3 of ground under local conditions, and to have a field check of the figures projected, a firing of two control wells should be scheduled; the wells should be the same size and with the same geologic features as the projected wells.

The location of these experimental wells should allow their subsequent opening and testing, if necessary.

Economic and engineering aspects of the thermal consolidation method under given conditions should be considered. This method is not justified economically when used in reinforcing the ground under small and non-critical constructions and when the formation subject to settling is thin (1-3m).

It should be kept in mind in planning a thermal consolidation with gas fuel that the cost break-down, as determined from a number of Ukrainian instances in 1956-1957, is as follows (in percentages):

Drilling	37.0
Fuel (coke gas)	2.9
Air (electrocompressors with a capacity of 6 m^3/min or 180 m^3/hr, each)	32.5
Labor	12.3
Material and equipment (cost of equipment on stock is not included)	14.5
Miscellaneous	0.8

It appears from this tabulation that the cost of fuel is only 2.9%, while that of drilling and air accounts for the bulk of the expenses (70% of the total). This is inadmissible. A lowering of this last figure should be the subject of special attention for the planner. This can be achieved by using portable mechanized rigs for drilling without water, thus eliminating the necessity of strengthening the well walls, and using cheaper compressed air sources operating at low pressures but with a high deliverability, instead of the present expensive electrocompressors of low deliverability.

Working Procedure

A few preliminary operations should precede the work of thermal consolidation. Among them are the following:

1) training in operational and safety procedures, of the supervisor, the crew foremen, and workers which are to work in three shifts;

2) clearing of the working area according to the project specifications and fitting or building of a temporary shelter for men and the control equipment;

3) digging the pit;

4) drilling of operating and control wells;

5) installing combustion chambers with shut-offs and sealing the well heads.

In addition to the latter operation, in highly permeable grounds the upper ground layer must be made less permeable for gases (surface tamping, clay, and concrete treatment, etc);

6) disposition and checking of equipment;

7) connecting the power, water, fuel, and compressed air lines;

8) connecting the fuel and air sources to burners and shut-off devices.

In view of the continuous nature of this work, each crew should have designated for it a foreman, a mechanic, a concrete mixer and a compressor man.

In preliminary operations, special care should be taken not to have the pits and wells flooded.

Thermal consolidation of ground under foundations is done in pits or trenches opened down to the projected foundation elevation or 0.5 m above it. Drilled in these diggings are 0.15-0.20 m holes, whose number and depth is specified in the layout.

In drilling, geologic data obtained during the reconnaissance should be checked against the newly obtained.

The drilling should be done without water. Drilling methods conducive to compaction of the well walls are not to be used.

In drilling from basements and other places where the use of long drill pipe sections is difficult, a percussion bucket tool should be used on a cable with a mechanical, electromagnetic, or pneumatic tool raising device (such as Engineer V. S. Posyada's pneumatic drill, etc).

Shut-off devices with combustion chambers are installed at the well heads. For this purpose, the well head is reamed out to 0.75 m, 0.7-0.75 m deep. To prevent the earth from falling into the hole, the latter is closed with a wooden plug 0.7-1.0 m long during reaming. With the reaming done, the plug is removed and the hole checked. In the event it is clogged up, it is carefully cleaned prior to installing the shut-off. The lower ceramic element is installed first (see Fig 6) by sinking it tightly into the ground at a depth of about half that of the funnel.

Then, in shut-off model one, the ring with a slit and a welded pipe for auxiliary cold air is fitted over the funnel and the upper and the middle funnels with a lid are installed. The gap between the combustion chamber walls and ground are tightly closed by concrete mixed with red brick rubble.

Installation of shut-off model two (see Fig 7) is simplified because there is no lower funnel or so-called lower air pipe illustrated in Fig 6.

This latter is designed chiefly for an easier firing-up, which is especially important in operations with liquid fuel. After a well has been changed over to normal fitting conditions, the flow of air through this pipe is not necessary.

Particular attention should be paid to installing the combustion chamber and the shut-off lid so as to have them as airtight as possible.

The warming-up and firing of wells is not done until the concrete has acquired 50% of its projected strength, i.e., not earlier than 3-4 days after the pouring. The concrete setting time can be cut down by burning some fuel in the combustion chamber without a pressure head. In this operation, the ceramic element of the chamber must not become red hot.

When a cast iron shut-off is used (see Fig 9), the well mouth is enlarged by moistening the ground and then pushing it aside with a heavy conic block attached to a vibrator.

With the top of the hole so enlarged, the block is removed, the hole is checked for debris, and the ceramic funnel is set tight in a clay slurry.

The lower part of a cast iron shut-off is installed after the ground surface by the wells has been tamped down with mechanical tampers, a concentric slit has been fashioned for the grounding of the shut-off spur, and the ground has been treated with fire-clay slurry.

A tripod and pulley are used in setting the cast iron slab, with the final fitting done with a vibrator. The tightness of fitting is checked with the appearance of the fire-clay slurry squeezed into control holes in the slab. When the moistened ground has dried out, these holes are closed with threaded cast iron chokes.

When the upper part of a pit is unconsolidated soil, the shut-off devices should be installed deeper, in denser, undisturbed horizons; otherwise, much hot gas will escape through these unconsolidated upper layers and the thermal process will not affect the lower and denser ground.

Burners and air and fuel hoses are then attached to the burners so installed.

Steel pipes and standard gastight flexible hose are used for distributing gas fuels and compressed air, with steel pipes and benzo-resisting flexible hose used for liquid fuel.

It is important to cut down as much as possible the length of flexible and, especially, benzoresisting hose, by replacing it with steel pipes and using it only in couplings.

<u>The firing up of a well with liquid fuel</u> and bringing it up to standard operating conditions is done as follows. The lower element of a heater (Fig 25), a metal rod or a tube 6-20 mm long, is wrapped in hemp fiber or rags which are then soaked in liquid fuel and ignited. A weak jet of fuel and air is directed to this torch with the burner. When the inner refractory element of the combustion chamber becomes red hot, the firing up is regarded as finished. The heater is removed from the well, the burner is fixed tight in the shut-off device, and the flow of fuel and air is increased to the required levels, in order to spread the burning down the well.

In firing-up, the combustion products escape through the shut-off outlet pipe (the lower air pipe).

The firing-up of a well requires about 1 kg liquid fuel and takes usually 15-25 min.

After steady working conditions have been established in the well, as signaled by a bright flame in the combustion chamber and the absence of smoke escaping through the shut-off outlet, the latter is closed with a stop-cock, then the lower air pipe is connected to it, and the well pressure is raised up to the specified level.

The firing-up of a well with gas fuel and bringing it up to the standard operating conditions is done as follows. First, compressors and the gas blower are connected, then the gas collector and air collector valves are opened. The air collector pressure is not raised above 1.1-1.2 atm. The excess pressure is bled off by the partial opening of free valves. The air-flow rate to the air collector should be raised gradually, as the number of operating wells grows; because of this, new air compressors are also cut in consecutively.

Air is conveyed only to the burners in small amounts necessary for the combustion process; accordingly, the valves in the shut-off air pipes are choked for this period. The incoming air is regulated by the burner's pilot wheel.

The gas pipe valves are then opened; first at the gas collector, then at the burner. At the same time, a burning match is touched to ignite the gas jet issuing from the burner.

The torch is regulated by controlling the flow of air and gas.

The ignited burner must be installed at the top of the shut-off device, with the torch directed into the well to the upper element of the combustion chamber; a gap should be left between the burner's lock sleeve and the opening in the upper lid of the shut-off. In this position, the burner is attached temporarily with a wire to the peephole tube (Fig 26).

When the refractory burning chamber becomes red hot, the burner is set up in its normal (vertical) working position and fastened with wedges. After that, the burning intensity in the well is raised gradually.

Time required for firing-up ten wells is not over 1.0-1.5 hrs. Firing with gas fuel is considerably simpler and faster than for liquid fuel. Moreover, a simpler shut-off device can be used.

In the process of thermal consolidation of ground, constant watch should be kept to maintain the well temperature at 750-1,000°C and a pressure of 0.3-0.5 atm. The combustion process is observed through the peephole.

The normal performance of a burner is characterized by a colorless flame in the combustion chamber and the absence of smoke.

A well should be heated up to red incandescence throughout its length. A darkening in the lower part of a well means a low pressure or an incomplete air shut-off seal.

Temperature equalization throughout the depth is achieved by lengthening the flaming gas torch through an increase in the pressure head; this stimulates a more intensive penetration of gases into the formation; as a result, the thermal process is speeded up and affects a wider zone.

In the absence of a pressure head in a well, during the firing-up the hot gas torch shrinks considerably, and the high temperature zone is concentrated in the upper well interval, with the hazard of fusing the well walls. The effectiveness of thermal consolidations drop sharply because of the small active radius, with the accompanying waste of time as well as fuel and air.

Red color with a whitish hue signals an inadmissible overheating of the well walls and their imminent fusing, which results in a virtual cessation of the hot gas circulation through the formation pores. This would lead to a ruin of the well and its replacement by another one.

The cause of such overheating is an excess of fuel over the amount specified and a deficiency in auxiliary air. When this happens, fuel should be cut off immediately and the well cooled off by pumping in cool air. When the well temperature drops to 700-800°C (not lower than 680°, the gas ignition point), the burner is switched to the normal firing conditions.

A more precise well temperature control is exercised with an optical pyrometer. In this operation, the firing is stopped at intervals not longer than 1 hr by choking the gas supply first from the gas collector (at the pump, when operating with liquid fuel), then at the burner by means of a corresponding reswitching of valves. After that, the burner is removed from its shut-off and the well is inspected. Finally, the well wall temperature is recorded by a pyrometer.

A normal firing should proceed at temperatures of 800-1,000°C; when the temperature rises above 1,000°C, the well walls must be cooled off.

With a persisting overheating of wells, suggesting a power deficiency in the compressed air sources, one or more wells should be disconnected and their share of air apportioned to the remaining wells. The temporarily disconnected wells can be refired after a break.

Particularly important is the maintenance of a necessary pressure head in wells; at the beginning and in the middle of the process, it must not drop below 0.3-0.5 atm, and not below 0.2-0.25 atm at the end of the operation.

The well pressure is checked every hour with a mercury or a spring gauge installed in the upper part of the shut-off device and graduated into millimeters (mercury column) or into 0.02 atm (spring gauge).

Should the well pressure drop because of a possible leak in the shut-off or through fissures formed about it, immediate repairs must be made. Fissures in concrete are filled with cement slurry, while calking with clay is used to stop the gas escape through the surface area.

One of the reasons for lower well-pressures is a wrong makeup of cycles, in which the wells are fired consecutively instead of alternately (or in a checkerboard pattern). In the latter instance, the gas escape is more uniform -- through the entire fired interval and into the immediate wells; this is not the case in the first instance.

Air coming in through the burners and shut-off devices maintains a well pressure of 200-350 mm mercury column or 0.25-0.50 atm.

The actual capacity of compressors after capital repairs is often below the certified; in a number of instances, it is down to 80-60% and even 50% of it. Because of this, it is necessary prior to the operation to check the actual capacity of the air compressing equipment, as well as the actual air consumption of each well during the operation.

A simple device can be used in measuring the air flow (see Fig 16). The pressure drop between two sections of pipeline is measured (in mm merc. col.) by a differential gauge (U-shaped glass tube 40-50% full of mercury or water); on this basis the actual air consumption is determined (Fig 27-b).

Let us assume, for instance, that we want to determine the hourly air consumption Q in cubic meters per well, for a measure pressure drop of h = 260 mm and with the following intial data:

1) pipeline diameter D = 50 mm;
2) diameter of the diaphragm orifice d = 25 mm;
3) air temperature t = 30°C;
4) barometric pressure P_b = 745 mm mercury column;
5) pressure of pumped air P_p = 760 mm mercury column;
6) consumption factor (with d/D = 0.5) a = 0.632;
7) volume weight of air under standard conditions γ = 1.204 kg/m^3;
8) absolute pressure $P = P_b + P_p = 745 + 760 = 1505$ mm m.c.;
9) pressure drop (as read on differential gage) h = 260 mm;
10) absolute temperature T = 273 + 30 = 303°K;
11) weight of water vapor in 1 m^3 of air (at t = 30°C) f = 0.0351 kg/m^3.

On the basis of these data, and using formula

$$Q = 0{,}00673 \cdot a \cdot d^2 \sqrt{\frac{P}{T}} \cdot \sqrt{\frac{h}{(r + f)\ (0{,}804 + f)}}$$

we determine the amount of air consumed in one hr:

$$Q = 0{,}00673 \cdot 0{,}632 \cdot 25^2 \sqrt{\frac{1505}{303}}\ \mathrm{x}$$

$$\mathrm{x} \sqrt{\frac{260}{(1{,}204 + 0{,}0351) \cdot (0{,}804 + 0{,}0351)}} = 94 \ \mathrm{m^3/hr}$$

The actual gas consumption in thermal strengthening of ground is checked with the same device as illustrated in Fig 16, but connected in a somewhat different way (Fig 27-a).

It should be kept in mind that, because of the very low gas expenditure for a single well and the small diameters of feeding pipes, a very small pressure drop is recorded by this device; not enough for precise determinations of the actual consumption. For this reason, the recording should be made on several simultaneously operating wells rather than on a single one. The procedure is identical to the one described above. Let us assume, for instance, that the pressure drop

for five simultaneously operating wells is h = 17 mm, with the following initial data:

1) pipeline diameter D = 50 mm;
2) diameter of the diaphragm orifice d = 25 mm;
3) temperature of coke gas t = 30°C;
4) barometric pressure P_b = 738 mm m.c.;
5) pressure of pumped gas P_p = 304 mm m.c.;
6) consumption factor (with d/D = 0.5) a = 0.632;
7) volume weight of coke gas under standard conditions γ = 0.436 kg/m^3;
8) absolute pressure P = P_b + P_p = 738 + 304 = 1042 mm m.c.;
9) absolute temperature T = 273 + 30 = 303°K;
10) weight of water vapor in 1 m^3 of air (at t = 30°C) f = 0.0351 kg/m^3.

With the formula

$$Q = 0{,}00673 \cdot a \cdot d^2 \sqrt{\frac{P}{T}} \cdot \sqrt{\frac{h}{(r + f)\ (0{,}804 + f)}}$$

we determine the volume of gas required in firing five wells for one hour:

$$Q = 0{,}00673 \cdot 0{,}632 \cdot 25^2 \sqrt{\frac{1042}{303}}\ X$$

$$X \sqrt{\frac{17}{(0{,}436 + 0{,}0351)\ (0{,}804 + 0{,}0351)}} = 32.5\ m^3/hr.$$

For a single 10 m deep well the coke gas consumption is

$$32.5 : 5 = 6.5\ m^3/hr.$$

Upon termination of thermal treatment of control wells, the actual dimensions of consolidated zones (diameter, depth) are ascertained by digging down to their total depth and opening trenches or pits with one of their walls abutting on the vertical axes of control wells.

The consolidated block around a well is sampled for laboratory tests for settling, shear, and compaction; if necessary, and when the customer so desires, specimens of the thermally consolidated ground may be tested for compression.

Thermal treatment of a well is regarded complete when the specified amount of fuel has been burned in it at a pressure head not lower than 0.25-0.50 atm and with the specified volume of air (25-30 m^3 for 1 kg liquid fuel or 10-15 m^3 for 1 m^3 coke gas, etc).

Technical reports should be kept of the work of thermal consolidation in all its stages, with timely certification of all latent work.

A general work report contains the following items:

1) preliminary operations and readying the work area;
2) digging pits;

3) drilling wells, and their dimensions;

4) correlation of actual and specified geologic conditions;

5) installation procedure for combustion chambers and shut-off devices;

6) arrangement and installation of equipment;

7) the order in which burners and shut-off devices are connected to fuel and compressed air and/or disconnected from them;

8) the firing-up method, time consumed in this operation, and the date of the beginning of normal firing operation, for each well;

9) measures taken to regulate the well temperature in normal operations and to combat a pressure drop;

10) reading of pressure gages installed on the air collector (receiver), gas collector, liquid fuel pump, shut-off devices, etc;

11) well temperature readings (by optical pyrometer);

12) data on fuel and air consumption, with systematic control measurements;

13) observations on safety measures.

A record of thermal consolidation, Form No 1 (see Appendix II), should be kept for each well, including the control ones. Accounts of fuel, air, and time consumed in thermal consolidation of ground for each object are kept on Form No 2 (see Appendix III).

Note: When an operation goes wrong and the well pressure drops below 0.2 atm, time and fuel wasted in the unproductive period are not included.

The following safety rules should be observed in the firing-up of wells and during the thermal operations:

1) Men working on firing-up and maintenance of the wells should always wear goggles and canvas gloves.

2) Strict attention should be paid at all times to the state and performance of the equipment (burners, shut-off devices, gas blowers, compressors, liquid fuel pumps, recording and control devices) and to the fuel and air pipeline system; particular attention should be paid to the couplings of hoses to each other and to metal parts to prevent their overheating and a leakage of fuel and air.

3) When a gas leakage is detected by odor or with control devices, the gas supply must be cut off immediately; the operation must be stopped and not resumed until all damage has been repaired as verified by appropriate inspection.

4) In the event of an unforeseen breakdown in the air supply (power line or compressor trouble, etc), the fuel supply must be cut off immediately, then the air supply; the burners should be removed from the shut-off devices and the openings should be covered by bricks (one brick to a shut-off device).

Note: A break in the thermal operation of a well should not exceed 30 min on the first day of work and 1-4 hrs thereafter.

5) Water must not be let into the wells.

6) Strangers are not to be admitted to the area of operating wells.

7) Only those who have taken a safety course are allowed to work in this field.

8) Men who service the burners and conveyers of fuel and air (compressors, air turboblowers, gas blowers, etc.) should have proper certificates of training.

9) Proper ventilation should be installed in closed working quarters and in deep and narrow pits.

10) Fuel tanks should not be placed closer than 5 m to operating wells.

Upon termination of thermal operations, the work is accepted by a special commission which draws up an act of acceptance. The acceptance procedure is as follows:

1) a spot check of the results (the number, dimensions, and arrangement of wells);

2) work records are checked, with particular attention paid to the well pressure, the air and fuel expenditure, the firing time for each well, and the absence of well wall fusing;

3) actual inspection of the dug-out consolidated zone in control wells, with its depth and diameter measured;

4) inspection of the laboratory test data on settling and shear of specimens from the consolidated ground of experimental locations.

The accepting commission may request a probing with the test rod and an opening of the upper part of a doubtful well in checking actual dimensions of its fired zone.

If these dimensions are not as specified, an additional firing of defective wells is done, or else new wells are drilled and fired. The time and conditions of additional work are specified by the commission.

After the act of acceptance has been signed, the wells are filled with earth, which is then tamped down tightly.

Any settling of foundations and buildings erected on grounds so reinforced should be observed, both during and after the construction. For this purpose, temporary bench marks should be fitted into the foundations, above ground, and tied in to permanent bench marks. During and after the construction, these local bench marks should be surveyed regularly to check their elevations.

CAPTIONS TO ILLUSTRATIONS

Fig.1, p 7: Installation scheme for thermal consolidation of grounds subject to settling, by the first method.
1) compressor; 2) cold air supply line; 3) air heating unit (a_1 -- furnace with coil; a_2 -- preliminary air heating by vented waste gases); 4) insulated hot air pipe; 5) well-head shut-off; 6) injection well; 7) thermal consolidation zone of ground.

Fig 2, p 7: Installation scheme for thermal consolidation of grounds subject to settling, by the second method (liquid fuel model).
1) compressor; 2) cold air supply line; 3) liquid fuel tank; 4) filter; 5) fuel pipe line; 6) pump injecting fuel into well, under pressure; 7) burner; 8) shut-off device with a combustion chamber; 9) injection well; 10) thermal consolidation zone of ground.

Fig 3, p 11: Jet nozzle for burning of liquid fuels in an injection well.
1) air tube with a nipple (a_1 -- for air necessary in spraying and burning the fuel; a_2 -- for excess air to regulate the well temperature); 2) fuel tube with a nipple; 3) valve with a regulating needle; 4) body of burner; 5) middle tubing; 6) inner tubing; 7) the jet shut-off valve; 8) nozzle; 9) diffuser.

Fig 4, p 11: Jet nozzle for burning of gas fuel in an injection well.
1) body of burner; 2) inside gas tubing; 3) gas flow regulator; 4) burner shut-off device; 5) diffuser; 6) pilot wheel to regulate gas flow; 7) tube with a nipple to convey gas from the distributor; 8) air tube with nipple; 9) valve with a pilot wheel to control air flow.

Fig 5, p 12: General view of the above-ground part of an injection well

Fig 6, p 13: Airtight shut-off device with a combustion chamber
1) combustion chamber; 2) heat insulating stuffing; 3) tubing to convey additional air to upper part of combustion chamber; 4) jet-burners; 5) pressure gauge; 6) peephole with the gauge elbow; 7) metal lid; 8) fastening of metal lid; 9) tubing for conveying excess air to lower part of combustion chamber; 10) wedges for fastening the burner; 11) anchor blots; 12) ceramic funnels of the combustion chamber; 13) fitting net of 6-mm thick steel (total weight, 3-4 kg); 14) concrete with red brick rubble; 15) hollow ring with a slit.

Fig 7, p 14: Airtight shut-off device with a combustion chamber for gas fuel.
1) tube for excess air; 2) peephole with a gauge elbow; 3) pressure gauge; 4) heat insulating stuffing; 5) ceramic funnels forming the combustion chamber; 6) fitting net; 7) the body lid with a wedge lock;

8) anchor bolts; 9) body of combustion chamber; 10) concrete with brick rubble.

Fig 8, p 15: General view of a refractory combustion chamber with a fixed metal lid
1) opening for the burner; 2) peephole; 3) stands for fastening the burner with wedges; 4) excess air tubing; 5) metal lid of the shut-off; 6) ceramic funnels of the combustion chamber.

Fig 9, p 16: Cast iron shut-off device
1) ceramic funnel -- lower element of the combustion chamber; 2) choke; 3) body of shut-off device; 4) stands for fastening the burner with wedges; 5) burner; 6) pressure gage; 7) peephole; 8) shut-off lid; 9) excess air pipe line.

Fig 10, p 17: Pumping unit for simultaneous servicing with fuel of 12-14 wells and more.
1) switch; 2) pressure regulator; 3) gear pump (5 liters/min or o.3 m^3/hr); 4) fuel meter; 5) electromotor (0.27 kwt); 6) base consisting of two coupled tanks; 7) pressure gauge; 8) stop-cocks with nipples for burner hoses.

Fig 11, p 18: General view of a pumping unit servicing simultaneously 12-14 injection wells, and more.

Fig 12, p 19: Diagram of fuel distribution to burners by compressed air.
1) compressor; 2) tank with capacity of 2-3 tons /metric/; 3) installation for conveying fuel by compressed air; 4) distributor; 5) well burners.

Fig 13, p 20: Installation for conveying compressed air and gas
1) electromotor- A-61 (N = 14 kwt; n = 1450 r.p.m); 2) gas collector; 3) RMK-2 water-ring pump (Q = 2.85 m^3/min); 4) reservoir-frame.

Fig 14, p 22: General view of a gas collector

Fig 15, p 22: General view of an air collector

Fig 16, p 23: Air and gas meter
1) nipples to connect differential gauge; 2) connecting rubber tubes; 3) diaphragm

Fig 17, p 24: Coring device for sampling thermally consolidated grounds
1) electrodrill; 2) cutting head; 3) thermally consolidated ground; 4) cylindrical disc.

Fig 18, p 26: Plan of the thermal consolidation work for ground under a five story apartment house
a) a four-cycle work schedule (cycle I -- wells Nos. 1-17; cycle II --

Nos 18-34; cycle III -- No 35-41; cycle IV -- No 52-68); b) a two-cycle work schedule (cycle I -- No 1-34: cycle II -- 35-68).

Fig 19, p 31: Distribution of thermally consolidated zones about a vertical well
a) with a 0.2-0.5 atm pressure head in the wells; b) with the pressure head missing.

Fig 20, p 32:

Symbols

——— compressed air pipeline
- - - - fuel pipeline

The equipment connection diagram in a simultaneous firing of 17 wells with liquid fuel.
a) first variant (with standless distributor hose):
1) compressor; 2) compressed air receiver; 3) storage tank for solar oil; 4) working fuel tanks;
b) second variant (with partial substitution of metal pipes for standless hose):
1) compressor; 2) compressed air receiver; 3) storage tank for solar oil; 4) fuel receiver; 5) pump.

Fig 21, p 33: The equipment connection diagram in a simultaneous firing of 12 wells.
1) compressor; 2) pipeline for compressed cold air; 3) receiver; 4) pressure pump for conveying fuel to wells; 5) fuel pipeline; 6) fuel tank; 7) wells.

Fig 22, p 34:

Symbols

——— compressed air pipeline
- - - - - fuel pipeline

The equipment connection diagram in a simultaneous firing of 15-17 wells, with liquid fuel
a) first variant (with standless distributor hose; b) with partial substitution of metal pipes for standless distributor hose:
1) stationary compressor with capacity of 30 m^3/min; 2) a 24 mm pipe compressed gas receiver; 3) working fuel tank; 4) pumping unit; 5) fuel vat.

Fig 23, p 35:

Symbols

——— air pipeline
- - - - - fuel pipeline

The equipment connection diagram in the simultaneous firing of 17 wells with gas fuel.

a) plan; b) coupling detail; 1) air blower; 2) gas pipeline; 3) gas collector; 4) air pipeline; 5) airtight shut-off with combustion chamber; 6) air collector (receiver); 7) jet burner; 8) air hose; 9) T-joint.

Fig 24, p 36: The equipment connection diagram in the simultaneous firing of 12 wells with coke gas
1) air collector; 2) portable compressors; 3) drainage; 4) gas blower; 5) gas pipeline; 6) water pipeline; 7) gas collector.

Fig 25, p 40: Firing-up of a well with liquid fuel
1) burner during the firing-up period; 2) heater; 3) shut-off; 4) rage (hemp fiber).

Fig 26, p 42: Firing-up of wells with coke gas
1) burner during the firing-up period; 2) temporary fastening of burner with wire; 3) gap 10-15 mm; 4) shut-off

Fig 27, p 44: Connection of diaphragm and differential gauge
a) in measuring the gas consumption: 1) gas blower; 2) diaphragm; 3) U-shaped differential gauge; 4) burner; 5) shut-off

Appendix I

EXAMPLE OF CALCULATION OF THE AMOUNT OF FUEL NECESSARY IN FIRING OF A 12 m DEEP WELL TO OBTAIN A CONSOLIDATED GROUND ZONE, DIAMETER 2 m

Initial data
(tons, when given, mean metric tons)

Volume of consolidated block	$V = \frac{\pi D^2}{4} h = \frac{3.14 \times 2^2}{4} \times 12 = 37.6\ m^3$;
Volume of weight of ground	$= 1.8\ tons/m^3$;
Humidity of ground	$W = 12.5\%$;
Weight of 1 m^3 dry ground	$P_1 = \frac{\Delta}{1 + 0{,}01\ W} = \frac{1{,}8}{1 + 0{,}01 \times 12{,}5} = 1.6$ tons;
Weight of water in ground pores	$P_2 = \frac{W\Delta}{100 + W} = \frac{12.5 \times 1{,}8}{100 - 12{,}5} = 0.2$ tons;
Initial temperature of ground	$t_1 = 0^oC$;
Average ground temperature, in firing	$t_2 = 700^oC$;
Heating capacity of solar oil	$Q_s = 10{,}000$ kg.cal/kg;
" " " coke gas	$Q_g = 4{,}500$ kg.cal/kg;
Heat capacity of dry ground	$C_1 = 0.2$ kg.cal;

Heat capacity of water	$C_2 = 1.0$ kg.cal;
Latent heat of vaporization	$C_v = 540$ kg.cal;
Fuel expenditure in heating 1 m^3 of dry ground to 700°C	$S_1 = P_1C_1\ (t_2 - t_1) = 1600 \times 0{,}2 \times 700 = 224000$ kg.cal;
Same for water, to the boiling point, in 1 m^3 of ground	$S_2 = P_2\ [C_2\ (100 - t_1) + Cv] = 200\ [1{,}0\ (100 - 0) + 540] = 128000$ kg.cal;
Total heat expended for 1m^3 of ground	$St = S_1 + S_2 = 224000 + 128000 = 352{,}000$ kg.cal;

Expenditure of solar oil

In firing of 1 m^3 of ground	$S_t : Q_s = 352{,}000 : 10{,}000 = 35.2$ kg;
For the total volume of 37.6 m of consolidated block	$35.2 \times 37.6 = 1323$ kg;

With 0.4 kg solar oil expended per one running meter of a well, per hour, the daily consumption will be:

$$0.4 \times 12 \times 24 = 115.2 \text{ kg}$$

The duration of firing of a single well is:

$$1323 : 115.2 = 11.5 \text{ days}$$

Expenditure of coke gas

In firing of 1 m^3 of ground	$S_t : Q_g = 352{,}000 : 4500 = 78.2\ m^3$.
For the total volume of 37.6 m^3 of consolidated block	$78.2 \times 37.6 = 2940\ m^3$;

With 1.0 m^3 coke gas expended for one running meter of a well, per hour, the daily consumption will be $1 \times 12 \times 24 = 288\ m^3$.

the duration of firing of a single well is:

$$2940 : 288 = 10.5 \text{ days.}$$

Note: The fuel consumption per unit of time and one running meter of the well is corrected depending on the gas permeability and fusing point of the ground.

Appendix II

Form No 1

Register No

THERMAL PROCESSING OF WELLS

Location

Well No

Well-head elevation

Diameter

Depth

Day and hour of the start of firing

Day and hour of the end of firing

Firing time (in hours)

Name and description of fuel

Fuel consumption (in kg or m^3)

		Pressure in kg/cm^2 or atm.						Fuel consumption from control and measurement data in kg or m^3.			
Date	Time of measuring	air collector	oil pump or gas collector	well	well temperature in C°	Firing time under uniform conditions, hrs	Total firing time	for 1 hr	for control period	total after the firing up	Remarks
1	2	3	4	5	6	7	8	9	10	11	12

Appendix III

Form No 2

GENERAL REGISTER

OF FUEL, AIR, AND TIME EXPENDED IN

THERMAL CONSOLIDATION OF GROUND

Location ______________________________

For wells No ______________________________

In the period from __________ 19__ to __________ 19__

Well No	Well diameter, m	Well depth, m	Day and hour of firing		Total firing time in hrs	Total fuel expended in kg or m^3	Total air expended in m^3	Average well pressure, in atm	Remarks
			start	finish					
1	2	3	4	5	6	7	8	9	10

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